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Report to Congressional Requesters

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June 1990

LOMA PRIETA EARTHQUAKE

Collapse of the Bay Bridge and the Cypress Viaduct

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The Honorable Jamie L. Whitten
Chairman, Committee on Appropriations
House of Representatives

The Honorable Glenn M. Anderson
Chairman, Committee on Public Works
and Transportation
House of Representatives

On October 17, 1989, the Loma Prieta Earthquake struck northern California, causing the collapse of a two-level, 1.25-mile-long section of the Cypress Viaduct on Interstate Route 880 in Oakland; 42 people were killed. A section of the Bay Bridge connecting San Francisco and Oakland also collapsed, resulting in one death.

In accordance with House Report 101-301, Further Continuing Appropriations, 1990, dated October 23, 1989, and subsequent agreements with your offices, this report provides information on (1) what the California Department of Transportation (CalTrans) knew about the structures' vulnerability to earthquake forces before they collapsed, (2) federal and state funding available and expended in California to strengthen bridge and viaduct[1] structures subject to earthquake forces, and (3) funding needed to complete California's seismic retrofit program.

Results in Brief

The Cypress Viaduct was 1 of about 9,700 bridges in California that were built before current earthquake standards. After the 1971 San Fernando Earthquake, CalTrans engineers realized that the support columns and decks on all bridges designed before 1971 were potentially vulnerable to earthquake damage. They began what evolved into a three-phase retrofit program to correct the deficiencies. Retrofit work was given lower priority than other safety projects and at the time of the Loma Prieta Earthquake—18 years later—CalTrans had completed one of the three phases. This phase corrected what CalTrans believed to be the most critical problem, the potential for deck sections to separate and collapse on all bridges considered to be vulnerable, including the Cypress Viaduct.

[1] While a bridge is an elevated structure over water and a viaduct is an elevated structure over land, we refer to both types of structures as bridges.

After studying the Cypress Viaduct's collapse, CalTrans engineers discovered a weakness in the Cypress' columns which they believe, when coupled with the effects of the earthquake on the soft soils underlying the structure, led to its collapse. This weakness was in addition to the deficiencies common to all bridge columns designed before 1971. CalTrans engineers believe they would have identified this weakness had the retrofit program progressed to phase three. They further believe that, had soil conditions been factored into the retrofit program's priority scheme, the Cypress Viaduct would have been scheduled for work sooner.

The San Francisco/Oakland Bay Bridge, also built before 1971, was reinforced in the mid-1970s to protect it against earthquake damage or collapse. However, CalTrans officials did not believe that the section which collapsed during the Loma Prieta Earthquake was vulnerable and had not reinforced it at this point.

According to FHWA officials, California has received over $5.5 billion in federal-aid highway assistance since 1975 (the first year for which information is available) for programs that include seismic retrofit projects as an eligible activity. Of the $4.2 billion available to CalTrans, CalTrans officials estimate that they spent about $54 million between 1971 and 1989 in federal and state funds to complete the first phase of the seismic retrofit program—tying together the road deck section of 1,261 bridges to prevent separation and collapse. The second phase—strengthening the columns of 392 or more single-column bridges—is scheduled for completion by December 1991 and will cost about $150 million to complete. The third and final phase—strengthening the columns of at least 700 multicolumn structures—is still being researched. As a result, a cost estimate is not yet available.

To centralize its control over the retrofit program and to help ensure that all work is completed by December 1993, CalTrans has been reorganized internally. However, the state has not yet committed sufficient funding to complete the program. The decision was deferred until after June 5, 1990. On that date, voters considered and approved a ballot measure intended to make additional transportation funds available.

Background

The vulnerability of bridges to earthquake effects was first brought to the state's attention in 1971, when the San Fernando Earthquake destroyed five Southern California bridges. The destruction demonstrated weaknesses in the existing seismic design standards for bridges,

particularly in road deck and support column design features. CalTrans therefore revised its design standards for the construction of new bridges in 1974, which were then adopted and periodically revised by the American Association of State Highway and Transportation Officials. The Association promulgates bridge design standards, which the Federal Highway Administration (FHWA) endorses for use on federally funded projects. Generally, to receive federal funding, states must demonstrate compliance with the Association's standards.

Bridges built before the standards were revised, however, needed to be strengthened to overcome the design weaknesses identified after the San Fernando Earthquake. CalTrans developed internal guidelines in 1975 for retrofitting to prevent deck separation and is currently working on guidelines for column retrofitting schemes. The Association, however, has not yet adopted retrofitting standards.

According to FHWA officials, federal-aid highway funds are available to states for seismic retrofitting through five programs: Consolidated Primary System; Secondary System; Urban System; Interstate Resurfacing, Restoration, Rehabilitation, and Reconstruction; and Bridge Replacement and Rehabilitation. However, FHWA does not earmark funds to meet seismic retrofitting needs; states spend the funds according to their own priorities. States generally match federal funds by contributing 10 to 25 percent, depending on the program, of a project's costs. States may not use federal funds for toll bridges such as the San Francisco/Oakland Bay Bridge, but Congress did allow emergency relief funds allocated after the Loma Prieta Earthquake to be used for repairing the San Francisco/Oakland Bay Bridge.

In California, the legislature determines the amount of CalTrans' budget and makes some determinations about how the budget should be distributed across the state. The California Transportation Commission is responsible for determining how these funds will be allocated among transportation programs and approves individual projects at the time projects are ready to be advertised.

Cypress Viaduct Had Known Weaknesses but Was Not Considered Likely to Collapse

At the time of the Loma Prieta Earthquake, CalTrans officials knew that the Cypress Viaduct, a double-deck, multicolumn structure built before 1971, had insufficiently reinforced support columns that were vulnerable to earthquake damage. Before the Loma Prieta Earthquake, no multicolumn bridge had collapsed during an earthquake. CalTrans officials anticipated that a major earthquake could damage the columns, but did not believe that the roadway would collapse. They now believe that, in addition to the reinforcement deficiencies common to all pre-1971 structures, the Cypress structure had other deficiencies in its columns, which engineers working on CalTrans' seismic retrofit program did not know existed, and which CalTrans believes may have led to the collapse.

The need for seismic retrofitting became apparent when the 1971 San Fernando Earthquake severely damaged five bridges and disclosed the need to tie bridge decks together and to reinforce support columns. After this earthquake, CalTrans revised its standards for new construction and began what evolved into a three-phase seismic retrofit program to strengthen bridges built before 1971. (See app. II for a detailed explanation of the program.) Correcting deck weaknesses, the first phase, was given priority because CalTrans believed that these weaknesses were both more serious and less expensive to correct. This work was completed on the Cypress Viaduct in 1977 and on a total of 1,261 structures by 1989. Column work was considered less critical and was planned for later phases of the program. In addition, technology was not available for column retrofit work and needed to be developed.

After studying the collapse, CalTrans engineers now believe that the Cypress Viaduct had an additional, more serious weakness in its columns which, when combined with the amplified shaking motions in the soft soils underlying the structure, led to its collapse. (See app. III for a discussion of earthquake force measurements.) According to CalTrans engineers, the reinforcement provided at the point where the columns joined the lower deck—the pedestal section—was insufficient to prevent the columns from breaking. (See app. I, figs. I.2 and I.3.) It was at this point that many of the columns sheared off, causing parts of the upper and lower decks to collapse. (See app. I, figs. I.4. and I.5.)

This design feature, according to CalTrans engineers, was only used on the Cypress Viaduct and six other viaducts built in San Francisco about the same time, which were severely damaged but did not collapse. CalTrans engineers working on the retrofit program after 1971 were not aware that any bridges contained this design feature and thus did not address it in the retrofit program. However, they now believe that an inspection

of the design and construction plans would have revealed the potential for collapse. CalTrans had not inspected these plans before the Loma Prieta Earthquake, but planned to do so during the third phase of the statewide retrofit program which, at the time of the earthquake, had not yet begun.

CalTrans engineers were aware that soft soils were layered throughout the San Francisco Bay Area, including the area under the Cypress Viaduct and the Bay Bridge, but had not systematically gathered the information or incorporated it into the process used to determine the need for and criticality of retrofit work. They now believe that, if soil information had been used as a priority factor in the retrofit program, the Cypress Viaduct would have been given a much higher priority.

Bay Bridge Damage Was Not Anticipated

Because of its exceptional size and complexity, the Bay Bridge is considered a "special structure" to which standard engineering codes and standards do not apply. As a result, its retrofit needs were independently assessed during the 1970s, and the bridge was equipped with deck restrainers and other devices at points considered susceptible to earthquake damage. The additional reinforcing of several of the piers has been planned since 1984. CalTrans did not consider the work urgent, however, and it was not scheduled for completion at the time of the Loma Prieta Earthquake. According to CalTrans officials, the section that collapsed was not previously considered vulnerable and an independent engineering expert, studying the collapse under a National Science Foundation grant, told us it would not have been affected by the additional reinforcement planned for the piers.

The collapsed section broke off of one of the strongest piers supporting the east bay section of the bridge. This pier was designed to absorb the energy of an earthquake and prevent shocks to other points along the bridge. According to CalTrans engineers, the unanticipated magnitude of the horizontal motion caused by the Loma Prieta Earthquake broke the bolts holding the span to this pier, causing it to fall. (See app. I, fig. I.6.)

CalTrans officials believe that a detailed structural analysis could have detected this section's weakness. However, the bridge was not considered vulnerable and, before the Loma Prieta Earthquake, such analyses were not performed because of their cost and complexity and because of the limited funds available. The analysis involves a computer simulation of how various shocks would affect about 27,000 possible stress points along the bridge's 8.3-mile length. CalTrans is now planning to conduct

detailed analyses of all seven San Francisco Bay crossings, as well as three large bridges in southern California. CalTrans officials estimate that the Bay Bridge analysis will cost about $300,000 and take a year to complete. The contract was awarded in April 1990.

Funding Available for Retrofit Work

CalTrans estimates it spent about $54 million from 1971 through 1989 to complete the first phase of its seismic retrofit program. Neither CalTrans nor FHWA officials can readily estimate the federal share of these costs. CalTrans did not separately account for funds spent on seismic retrofitting until after the Loma Prieta Earthquake. However, CalTrans budget officials normally estimate the federal share at 85 percent when preparing budgets. This ratio would place the federal share of the seismic retrofitting work at about $46 million.

FHWA has allocated more than $11 billion in federal-aid highway funds to California over the last 16 years to support transportation projects. Of this amount, over $5.5 billion was allocated for four programs which included seismic retrofitting work as an eligible activity: Interstate Resurfacing, Restoration, Rehabilitation, and Reconstruction; Consolidated Primary System; Secondary System; and Urban System. According to FHWA officials, CalTrans could use the $4.2 billion available under the Interstate 4R, Primary, and Secondary programs to support its activities. The $1.3 billion made available to the state under the Urban System program was passed on to local governments.

Funds from the Bridge Rehabilitation and Replacement Program may also be used for retrofitting work. However, it was not until 1990 that FHWA, in response to the Loma Prieta Earthquake, allowed bridge funds to be used on projects specifically designed to correct seismic deficiencies. Previously, these funds could be used for seismic retrofitting work only when it was done in conjunction with other rehabilitation work.

Although seismic retrofitting work is eligible for funding under four federal-aid highway programs, the federal government does not specify the amount of funds to be spent for such work. States determine how much to spend for seismic retrofitting work on the basis of their own needs and priorities. According to FHWA officials, California has been a leader in researching and performing seismic retrofitting.

In response to the Loma Prieta Earthquake and Hurricane Hugo, the Congress approved $1 billion in emergency relief funds which is available to repair highways and bridges damaged by these disasters. Some

of these funds will be applied to the Bay Bridge repair costs and will be used to repair and retrofit other bridges damaged during the earthquake, including the Embarcadero, China Basin, Southern, Alemeny, Terminal Separation, and Central viaducts in San Francisco. The emergency relief funds can also be used to rebuild the Cypress Viaduct.[2]

Before 1987, some retrofit projects were included in CalTrans' State Transportation Improvement Plan, but funding was approved on a project-by-project basis after the projects were ready to be advertised for contract. After the 1987 Whittier Earthquake, the California Transportation Commission approved CalTrans' request to set aside a lump sum for the second phase of the seismic retrofit program. CalTrans proposed to use $64 million of its budget (which included funds from both state and federal sources) over 4 years to strengthen single-column bridge structures.

After the Loma Prieta Earthquake, the state legislature appropriated CalTrans $60 million from the state's disaster relief fund for retrofitting needs.[3] The legislature anticipated that this appropriation would be supplemented by federal funds. To raise the $60 million and to provide funds for other emergency relief needs, the legislature imposed a 13-month, quarter-cent sales tax increase. The legislature also mandated that all retrofit work be completed by December 1991.

Cost to Complete the Retrofit Program Is Unknown

CalTrans has not yet estimated the cost to complete all phases of the statewide retrofit program. Officials have estimated it will cost $150 million to complete most of the second phase of the retrofit program—strengthening the support columns on 392 single-column bridges which need retrofitting. This amount could include over $127 million in federal funds and could increase as CalTrans continues to screen structures for retrofitting needs. CalTrans anticipates that this work will be completed by December 1991.

CalTrans does not know how much funding will be required to complete the third phase of the program—strengthening the support columns on multicolumn bridges. Although screening has not been completed, CalTrans officials estimate that at least 700 such structures will need

[2]We are currently reviewing the cost and status of the emergency relief program for California and its impact on the Highway Trust Fund.

[3]The legislature appropriated an additional $20 million to retrofit local bridges.

retrofitting. In addition, the technology to retrofit multicolumn structures is still being researched. As a result, CalTrans will not be able to complete this work by the legislature's December 1991 deadline, and has asked for an extension until December 1993. Because multicolumn bridge structures are more complex than single-column structures, CalTrans officials expect the costs for multicolumn bridges to be higher. CalTrans officials said an estimate for phase three work would not be available before December 1990.

CalTrans Has Upgraded Priority of Seismic Retrofitting Work, but Future Funding Is Uncertain

In past years, retrofitting work has been given lower priority than other safety projects. The first phase took 18 years to complete. Retrofit projects were identified by CalTrans headquarters and assigned to the appropriate districts for completion. However, the districts received no additional resources specifically for retrofitting work. As a result, retrofit projects competed with other locally identified projects for priority and resources. According to CalTrans officials, safety and rehabilitation projects were assigned priority based on the number of lives lost in previous incidents. Thus, retrofit projects were accorded a relatively low priority because, until the Loma Prieta Earthquake, earthquake damage to state bridges had resulted in the loss of only two lives. Other projects, such as installing guard rails and median barriers, tended to take precedence because they were viewed as more critical to improving highway safety.

As the phase one screening was completed and the appropriate district offices were notified of which bridges needed to be retrofitted, neither CalTrans nor the California Transportation Commission monitored the retrofit program's progress. Some districts completed the work quickly, while others did not.

Although CalTrans received approval in 1987 to reserve $64 million for retrofitting single-column bridges and viaducts, projects were not forwarded for funding until after the 1989 Loma Prieta Earthquake. According to CalTrans officials, some project designs were completed by June 1988, but funding problems and engineering resource constraints prevented their completion. As a result, the districts did not complete the site work needed to forward the projects for funding approval. Consequently, as of April 1990—30 months after the 1987 Whittier Earthquake—no single-column retrofit projects had begun construction. However, three contracts were awarded in March 1990, and eight others had been advertised.

According to CalTrans officials, seismic retrofitting work will no longer compete with other projects for resources. To ensure that all retrofitting work is completed by December 1993, CalTrans has shifted engineering resources from the districts to headquarters to work solely on retrofit projects. CalTrans has also established a separate budget for seismic retrofit projects and appointed a Seismic Retrofit Program Manager, who will oversee the projects to ensure that all necessary work is accomplished. Further, CalTrans is incorporating soil information into the data base maintained on the state's bridges, and is working on a plan to incorporate the information into the seismic retrofitting program. In addition, CalTrans is providing the California Transportation Commission with monthly progress reports.

Funding to Complete Retrofit Program Is Not Assured

CalTrans new emphasis on retrofitting leaves open the question of where it will find the funds necessary to complete its program. Although CalTrans is responsible for identifying state highway projects and establishing priorities, the California Transportation Commission determines how available funds will be spent and which of CalTrans' proposals will be approved for funding. As of May 1990, the Commission had not determined how it would make funds available to supplement the $60 million appropriated by the legislature for seismic retrofitting work.

When the state legislature appropriated the $60 million from its emergency fund, it required that these funds be used to match federal funds to support the retrofit program. Commission officials anticipated that the emergency relief funds appropriated by the Congress after the Loma Prieta Earthquake could be used for this purpose. However, according to FHWA officials, federal emergency relief funds cannot be used for routine retrofitting work. Instead, the $60 million could be used to match federal funds from the state's annual federal-aid highway allocation. Assuming a 15-percent matching share, the $60 million state share could provide a total of about $340 million in federal-aid highway funds for the program. The proposed 1990-91 budget includes $291 million for seismic retrofit projects: $25 million in state funds and $266 million in federal funds. Because the costs to retrofit multicolumn bridges are expected to be higher than those for single-column bridges, $400 million may not be sufficient to complete all retrofitting work needed on the state highway system.

In any case, an anticipated shortfall in California's revenues could prevent the state from completing many transportation projects, including seismic retrofit work. State budget analysts have projected that by June

1994, the cumulative shortfall in the transportation budget will reach $4.5 billion in state and federal funds. To generate additional funds, the governor and legislature have approved an increase in the state gasoline tax. This increase will take effect as a result of voters' approval of a June 1990 ballot measure to increase the state's spending limit, which was passed by the voters in 1979.[4] Raising the cap will allow the state to spend the additional gasoline tax revenues on highway projects.

But even if the additional state revenues are realized, funding the balance from California's normal federal-aid highway program would require a substantial reallocation of funds already planned for other construction projects. According to the California Transportation Commission, the proposed 1990-91 budget would use $266 million, or 40 percent, of the state's federal-aid program allocation. To prevent the delay of other construction projects, the Commission has recommended that the legislature appropriate additional state funds to the retrofit program. These funds could come from the state's general fund or from the emergency funds generated by the temporary sales tax. To date, the legislature has not acted on this request.

Conclusions

Although California's three-phase seismic retrofit program was started 18 years ago, only the first phase has been completed. CalTrans gave higher priority to other highway projects considered more critical to highway safety. We recognize that making decisions regarding such priorities is difficult because of the number of important projects which compete for the funds available. However, had the retrofit program progressed to the third phase before the Loma Prieta Earthquake, CalTrans engineers believe they would have identified the flaw which they now think was a major contributing factor in the Cypress Viaduct's collapse. With respect to the San Francisco/Oakland Bay Bridge, CalTrans officials thought that it had been sufficiently retrofitted prior to the earthquake and did not consider it susceptible to collapse.

In the wake of the Loma Prieta Earthquake, California has begun to focus more attention on completing its retrofit program. The state legislature has appropriated some of the funds needed for this work, and CalTrans has created a separate budget and dedicated staff specifically for this effort. These are the types of actions needed if the retrofit program is to be completed by 1993. Actions taken after both the 1971 San

[4]The cap limits expenditures by state and local governments to 1979 levels which have been adjusted annually according to various factors, including changes in population and the cost of living.

Fernando and the 1987 Whittier Earthquakes were not sufficient or sustained long enough to ensure the program's completion. Only time will tell whether future actions will be sufficient to ensure that the retrofit program is completed as soon as possible.

Agency Comments

In commenting on our report, CalTrans said that (1) our report should offer recommendations to help the Congress resolve the major policy decisions regarding a nationwide seismic safety program for transportation; (2) California is committed to completing an aggressive, expedited seismic retrofit program; and (3) the only outstanding question is the federal government's commitment to a comprehensive seismic retrofit program. Of these issues, this report addresses only California's commitment to an expedited seismic retrofit program. We were not asked to review the need for a nationwide seismic safety program or the federal government's commitment to California's retrofit program. Specifically, our work focused on what CalTrans knew about the condition of the two collapsed structures, what funds were available and have been spent on seismic retrofit work in California, and what funds will be needed to complete California's seismic retrofit program.

We recognize that California has renewed its attention to seismic retrofit work and has taken steps to complete it. However, past commitments have not resulted in the actions needed to correct deficiencies identified more than 18 years ago and, even with its current interest in the program, the commitment of funds needed to complete the program remains an outstanding issue.

With respect to CalTrans' comment that the only outstanding question is the commitment of the federal government, the federal government has provided CalTrans over $4 billion since 1975 for federal-aid highway programs that included seismic retrofit work as an eligible activity. Although it is not realistic to suggest that all of these funds should have been used for seismic retrofit, the fact that CalTrans spent about 1 percent of these funds, about $46 million, on seismic retrofit projects reflects how the state set its priorities and commitment to seismic safety during this time period. The complete text of CalTrans' comments are contained in appendix IV; our comments follow.

We also discussed the contents of this report with FHWA officials responsible for seismic safety activities. They said that, in their view, the report provides a fair and accurate account of the issues addressed. At their suggestion, a few minor technical changes were incorporated

where appropriate. Official comments from the U.S. Department of Transportation were not obtained.

We conducted our work from October 1989 to May 1990 at the California Department of Transportation and FHWA in Sacramento, California, and Washington, D.C.; interviewed agency officials; and reviewed official files, policies, and federal-aid highway program information. We also reviewed reports and studies on the Loma Prieta Earthquake and the resulting damage. We performed our work in accordance with generally accepted government auditing standards. Details of our objectives, scope, and methodology are contained in appendix V.

As agreed with your offices, unless you publicly announce its contents earlier, we will make no further distribution of the report until 30 days from the date of this letter. At that time, we will send copies to other interested congressional committees, the Department of Transportation, and the state of California. We will also make copies available to interested parties upon request. If you or your staff have any questions on this report, please contact me on (415) 556-6200 or Kenneth M. Mead, Director of Transportation Issues, on (202) 275-1000. Other major contributors to this report are listed in appendix VI.

Thomas P. McCormick

Thomas P. McCormick
Regional Manager

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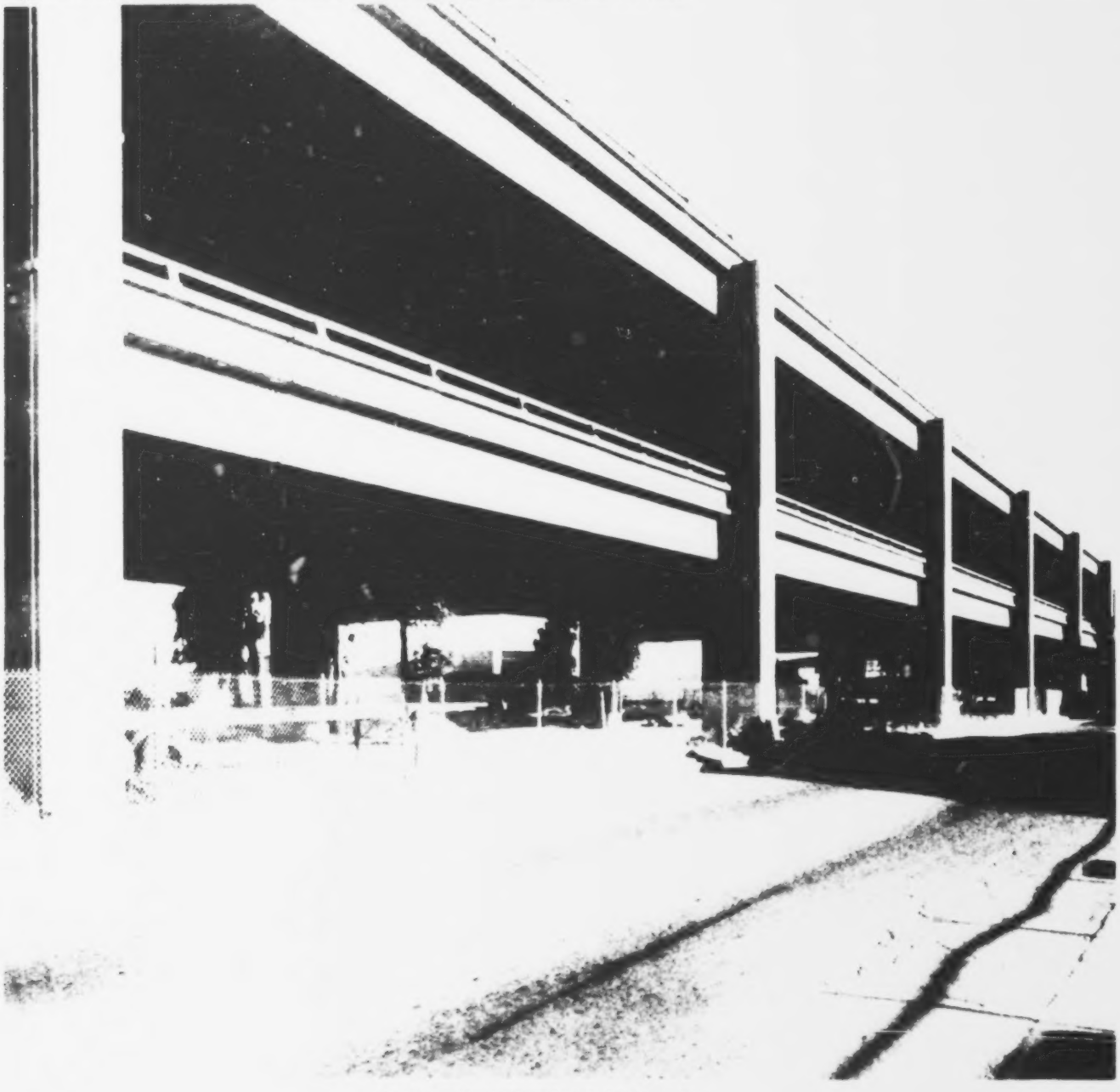
Abbreviations

CalTrans	California Department of Transportation
FHWA	Federal Highway Administration
RCED	Resources, Community, and Economic Development Division

Appendix I

Pictures and Illustrations of Cypress Viaduct and Bay Bridge Damage

Figure I.1: Cypress Viaduct Prior to Loma Prieta Earthquake of October 17, 1989



Source: California Department of Transportation

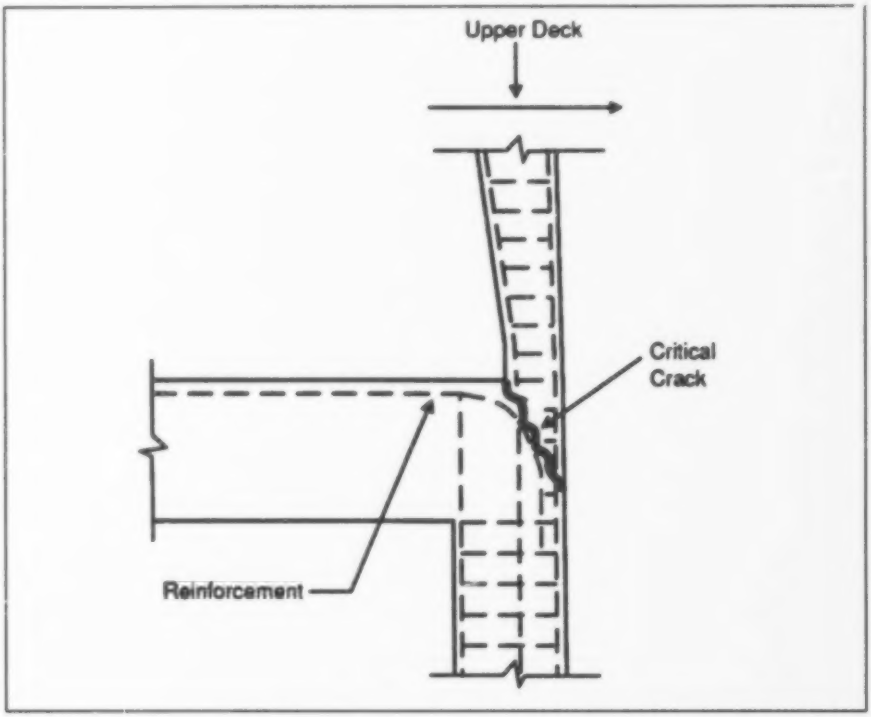


Figure I.2: Illustration Depicting Reinforcement in Cypress Viaduct Columns

Source: California Department of Transportation

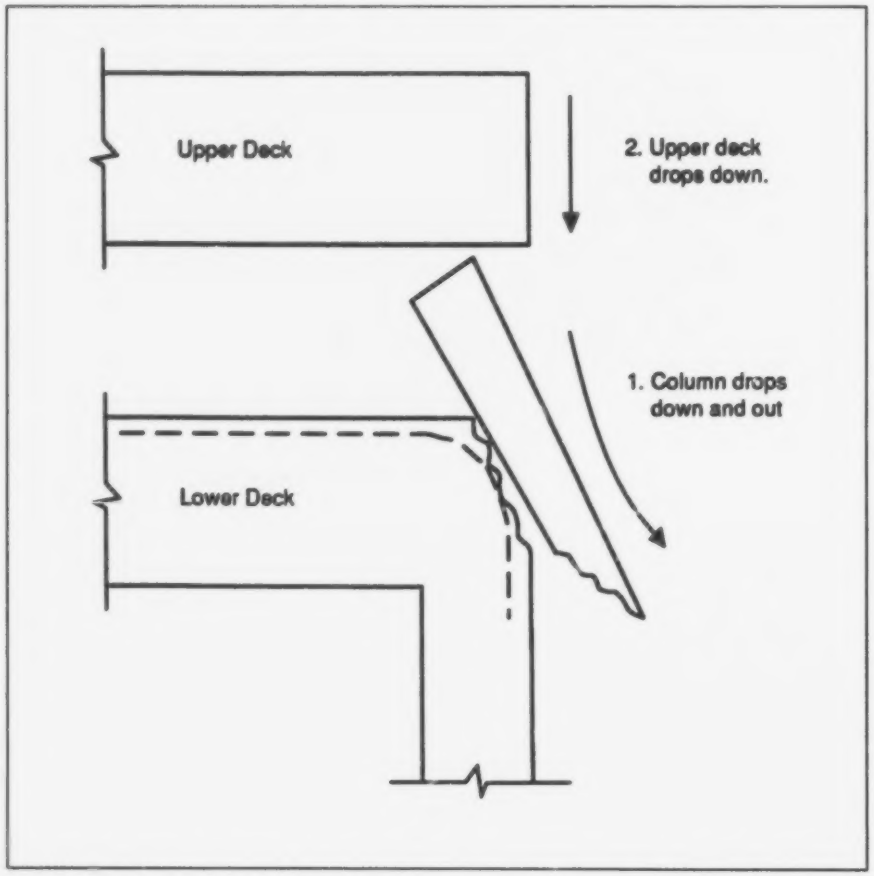
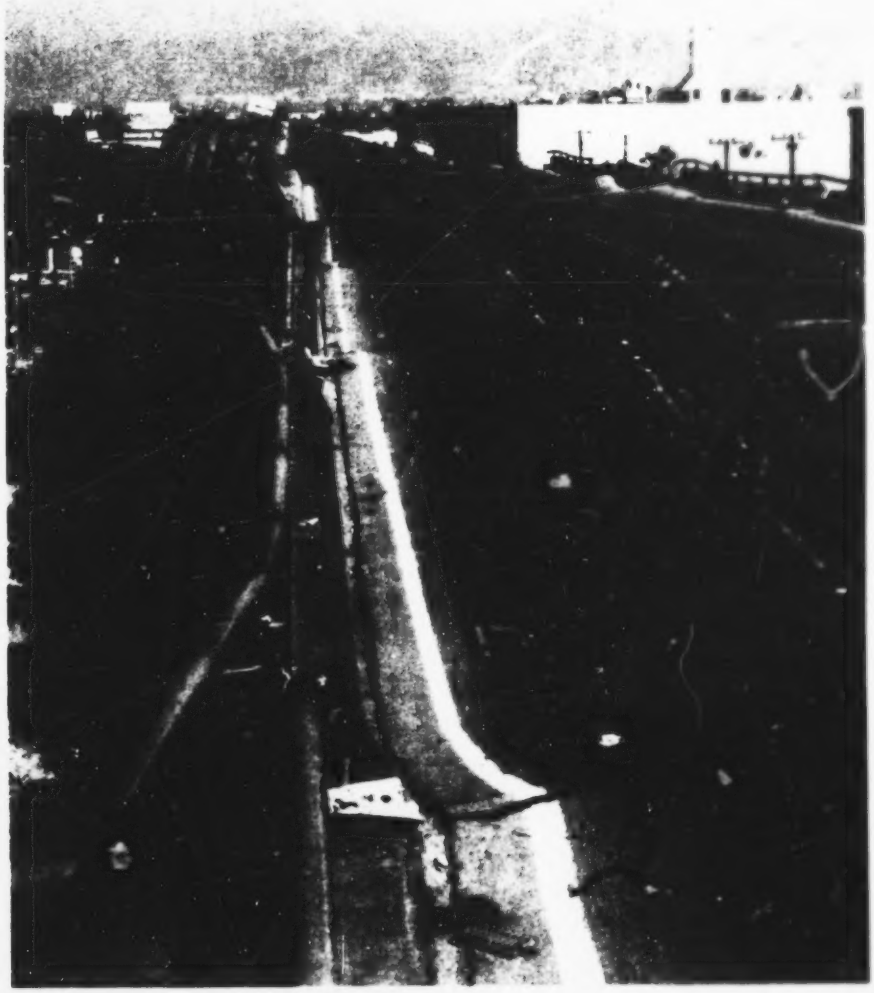


Figure I.3: Illustration Depicting Typical Cypress Viaduct Support Column Failure

Source: California Department of Transportation

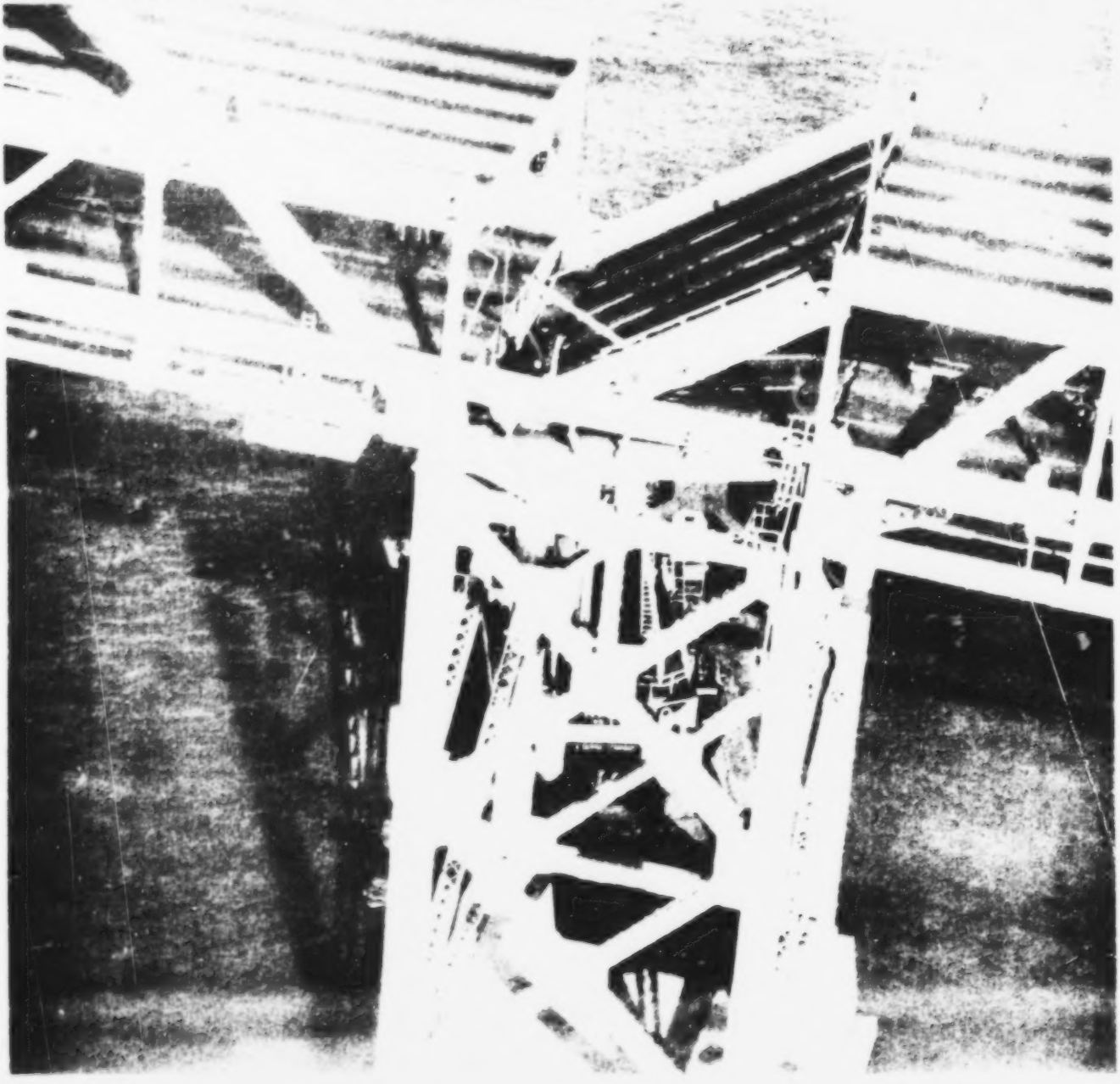
Figure I.4: Cypress Viaduct After October 17, 1989, Collapse

Figure I.5: Cypress Viaduct's Upper Deck Road Surface After October 17, 1989, Collapse



Source: California Department of Transportation

Figure I.6 Collapsed Section of the San Francisco Oakland Bay Bridge



California's Seismic Retrofit Program

The need for seismic retrofitting became apparent when the 1971 San Fernando Earthquake severely damaged five bridges in Southern California. As a result, California began what evolved into a three-phase seismic retrofit program to strengthen structures located in areas of frequent seismic activity to prevent similar damage from future earthquakes. Three types of weaknesses were identified for correction:

- Deck sections that were not adequately tied together at the hinges had a tendency to separate and collapse.
- Single columns that supported some structures were likely to suffer damage and possible collapse because of insufficient reinforcement, which allowed concrete in the columns to crumble.
- Multicolumn structures, including double-deck structures such as the Cypress Viaduct (see fig. I.1), were also considered vulnerable due to insufficient reinforcement. But because of the additional stability provided by multiple support columns, they were not considered as vulnerable as single-column structures. Before the Loma Prieta Earthquake, no multicolumn bridge had collapsed during an earthquake.

Correcting deck weaknesses became the first phase because the California Department of Transportation (CalTrans) believed these weaknesses were both more serious and less expensive to correct. CalTrans planned to reinforce the hinges between deck sections by tying them together with cables or other reinforcers. This work was completed on the Cypress Viaduct in 1977 and on a total of 1,261 structures by 1989.

Next, CalTrans planned to strengthen single-column structures by encasing the concrete columns in steel jackets. Although column damage was originally observed in the 1971 San Fernando Earthquake, the October 1987 Whittier Earthquake caused further bridge damage, reinforcing the need to strengthen columns on bridges built before 1971. The California Transportation Commission approved CalTrans' request to spend $64 million on these projects in December 1987. Research began in 1987, and the first contract was awarded in March 1990. CalTrans plans to have this phase completed by December 1991.

Finally, CalTrans planned to retrofit multicolumn structures—the third phase. This phase, which included the Cypress Viaduct, had not been scheduled at the time of the earthquake. The technology needed to retrofit multicolumn structures is being researched and is not yet fully developed. CalTrans plans to have the third phase completed by December 1993.

Earthquake Force Measurements

Earthquake effects can generally be categorized by two measurements. The Richter scale measures the energy release of an earthquake at its epicenter, while ground acceleration measures the gravity, or "g" force, of the ground-shaking motions. The g force can vary considerably according to the type of ground material involved and is more meaningful than Richter scale measurements to engineers designing bridges or buildings. The Loma Prieta Earthquake measured 7.1 on the Richter scale at its epicenter, near Loma Prieta peak in the Santa Cruz Mountains, where the ground acceleration ranged from 0.47 g to 0.64 g. No measurement devices were placed on the Bay Bridge or the Cypress Viaduct, about 60 miles from the epicenter. Devices near the Cypress Viaduct measured the ground acceleration at between 0.26 g and 0.29 g. This is in contrast to measurements of 0.11 g and 0.13 g in San Jose, located between the epicenter and the Cypress Viaduct, and 0.06 g at Yerba Buena Island, which anchors the middle of the San Francisco/Oakland Bay Bridge.

Geologists attribute the variations in ground acceleration to differences in soil composition; soft soils experience stronger ground shaking than hard soils. The collapsed sections of the Cypress Viaduct and the Bay Bridge were built on relatively soft soils, while Yerba Buena Island is on bedrock. The effects of earthquakes on soft soils were not fully realized by Caltrans until 1985, when the Mexico City Earthquake caused severe ground shaking and liquefaction, the loss of ground strength when loosely compacted, water-saturated sediments liquefy, in parts of the city built on landfill.

Comments From the California Department of Transportation

Note GAO comments supplementing those in the report text appear at the end of this appendix

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GAO Report on the Loma Prieta Earthquake

After the Loma Prieta earthquake on October 17, 1989, the California Department of Transportation (Caltrans) welcomed the General Accounting Office auditors in the hope that they would make recommendations to Congress on the appropriate way to address seismic safety concerns as they relate to the transportation system.

See comment 1

We believe the report should offer recommendations to help Congress resolve the major policy decisions regarding a nationwide seismic safety program for transportation. Unfortunately, the report suggests by implication that the Caltrans program, although acknowledged to be the leader in the country, is lacking in scope, timing, funding, priorities and commitment. Additionally, other than to note the most obvious of facts that the advanced California program did not prevent the severe damage experienced in the Loma Prieta earthquake, the report provides absolutely no guidance for California, for other states or for the nation as a whole on the development of an appropriate seismic retrofit program. No existing standards for such a program are identified, no comparisons are drawn and no suggestions are made for the development of needed programs.

See comment 2

Contrary to comments repeatedly made in the report, California is committed to complete a most aggressive, expedited seismic retrofit program. It will be completed within a few years at a cost of hundreds of millions of dollars.

See comment 3

The only outstanding question is the commitment of the federal government. Will it persist in its current policy of hiding from the problem and requiring the normal federal aid programs to be diverted to the seismic safety effort? If it does, California's normal federal-aid program will suffer very seriously, but California's seismic retrofit program will be completed.

What does the federal policy of ignoring the issue mean to other states? Should they likewise continue to ignore the issue? Should they shut down their normal federal-aid programs to pursue aggressive seismic retrofit efforts like California's? Should they take something from the federal-aid programs to start a well-planned long range retrofit program at a level that does not interfere with the basic priorities (i.e. traffic safety) of the federal-aid program?

The report provides no guidance on the most important, fundamental questions. In fact, it does a disservice by refusing to recognize how complex and difficult these public policy choices are, and by criticizing by implication the nation's most advanced seismic retrofit program because it tried to make those choices and tried to balance, within constrained funding seismic retrofit work with other safety and performance objectives of the federal-aid programs.

See comment 4

California has been a national and international leader in the structural and seismic research area for many years. Seismic design criteria used by the other 49 states have come from Caltrans' advanced seismic research and design programs. The GAO report does not explain the background and reasoning for decisions made during the past 20 years regarding the seismic strengthening of bridges in California. We believe this document should provide a framework by which the Congress of the United States can develop guidelines to help the states adequately deal with the seismic safety problem across the country.

I would suggest the following points must be considered so that the Congressional Oversight Committees can make informed decisions in developing directions to improve the seismic safety of our nation's transportation system.

* Over the years, California - and to the best of our knowledge every other state has followed the principle that we could expect and accept earthquake damage on highway structures but not accept collapse that could result in serious injury or death. This policy was based on the national and international research, state-of-the-art technology and the knowledge gained by Caltrans engineers from actual experiences in earthquakes in California and around the world.

* Prior to 1971, the department had developed a standardized design based on the available knowledge of the time. Structural engineering is a dynamic discipline, constantly evolving and changing. Advances in technology and knowledge are continually incorporated into designs. This applies to both buildings and highway structures. A building or highway

bridge designed in 1990 contains seismic design standards and features that are not found in structures 20, 30 or 50 years old.

* The 1971 San Fernando earthquake was a watershed event which Caltrans engineers used to expand their knowledge base and to make improvements to structures with the goal of preventing collapse. In this earthquake, columns experienced unanticipated damage and five bridges collapsed when the decks were pulled off their supports. From that quake, new design criteria were developed to strengthen columns and special priority was given to a retrofit program to prevent collapse by securing bridge decks to their support columns through the use of hinge restrainers.

* Factual evidence from subsequent earthquakes, including the 1987 Whittier Narrows event, confirmed that hinge restrainers should be the top priority in a retrofit program.

* After the 1987 Whittier Narrows quake, the department accelerated its research program into the strengthening of columns, with an emphasis on single column structures, as a way to minimize damage so repairs could be made without closing vital thoroughfares to traffic. This approach was confirmed by the 1988 earthquake in Armenia where thousands died when emergency vehicles were unable to reach victims because the road system was unusable.

* California's seismic program has been a major undertaking. It involved extensive new research, review and screening of thousands of structures and thousands of hours of work by Caltrans staff and consultants.

* Multi-column structures have as a class performed very well in quakes prior to Loma Prieta, including San Fernando and Whittier. There had been some damage, but no collapse.

* Loma Prieta produced a number of expected and unexpected occurrences. Hinge restrainers were effective and the new column design criteria incorporated into structures designed after 1971 performed as intended. As expected, repairable damage occurred to some structures. Collapse of the Cypress Viaduct and the section of the Bay Bridge was not expected.

* The Cypress Viaduct was designed and constructed to a strength exceeding the standards of the day. The structure was built to those standards and was meticulously and properly maintained over the 32 years since its opening in 1957. The same is true for the San Francisco-Oakland Bay Bridge, which was opened to traffic in 1936.

* Caltrans engineers were unaware of the potential for collapse at Cypress. There was no indication that the Cypress Viaduct was uniquely vulnerable. Of course with the benefit of hindsight, we have been able to identify a design detail that contributed in combination with other factors to this catastrophe. But before the October 17 earthquake, there was absolutely no evidence that would have prompted the department to conduct an exceptional detailed study of the structure.

* As a result of the Loma Prieta Earthquake, Caltrans has taken the following steps:
1. Examine all bridges in California for their potential for vulnerability in an earthquake.
2. Embark on an accelerated seismic retrofit program for all bridges.
3. Develop a response spectra for soft soils.

We believe that the installation of hinge restrainers kept many bridges from collapsing during earthquakes in California since 1971 including Whittier and Loma Prieta, saving hundreds of lives. Not only did the hinge restrainers keep the structures from collapsing on vehicles, but they also helped keep these structures intact and serviceable, allowing emergency vehicles to get aid to damaged areas of the community.

See comment 5

Were the Cypress and Bay Bridge strong enough to withstand the forces experienced during this earthquake? Obviously not. To suggest that there was a "design flaw" or that Caltrans ignored the problem is not backed up by the facts.

The GAO report has three major areas that need clarification:

1. SCOPE OF THE RETROFIT PROGRAM
Following the 1971 earthquake, the department embarked on a seismic retrofit program focused on efforts to prevent collapse of structures. The problem at San Fernando was corrected through the use of hinge restrainers. Further, it was identified that additional column strengthening would help reduce damage and not require closure of vital thoroughfares while repairs were made. Only after the Whittier earthquake did we make any distinction between single and multi-column bridges. That distinction was driven by the state of seismic research which offered some possible approaches that could be tested and used to retrofit single column bridges. Even then, there was no technology available for retrofitting multi-column bridges.

See comment 6

2. VULNERABILITY OF THE CYPRESS STRUCTURE
There was NO evidence or indication prior to October 17, 1989 that Cypress was uniquely vulnerable to collapse.

See comment 7

Consequently, there was no reason to undertake a study in which Caltrans engineers might have noticed the structure's unique design detail or that the amount of reinforcing steel in the columns was less than current requirements. In fact, hinge restrainers had been installed at Cypress to correct the problem that had been well documented at San Fernando and subsequent earthquakes.

3. ALLOCATION OF FEDERAL-AID HIGHWAY ASSISTANCE

See comment 8

The question of how best to use the resources to address the wide range of problems on our transportation system presents a most complex issue of public choice. How much is enough for seismic research and retrofit when (a) You are already addressing the vulnerability of bridges slipping off their supports that had been identified at San Fernando, (b) You have already updated your design criteria and (c) There is no indication of the possibility that any structure was vulnerable to collapse due to column failure. In California, the retrofit work to prevent collapse (for user safety) had been completed. The choice facing California, based on what was known prior to the Loma Prieta earthquake, was a choice between investment to provide new services and increased operational safety or investments to protect the services relying on older facilities.

The Loma Prieta Earthquake was a tragedy, but it would be an even greater disaster if we fail to learn from this experience, expand our knowledge and make improvements to the nation's transportation system. To reach that goal, the California Department of Transportation believes the Congress needs to provide guidance on funding priorities and the scope of the program needed on a nationwide basis to strengthen the transportation system in the event of a major earthquake. Earthquakes are more than just a California phenomenon. They are a national problem.

I have attached some additional comments to the GAO report which I believe will help the Congress deal with this very important issue.

Sincerely,

ROBERT R. BEST
Director

GAO REPORT ON THE LOMA PRIETA EARTHQUAKE

The following specific comments regarding the text of the report are provided in addition to the points presented in the cover letter.

Pages 1 and 2 regarding "RESULTS IN BRIEF"

For all the reasons discussed in our cover letter we feel your summary does not fairly present the State's program.

Page 4, the first full paragraph is incorrect and should be rewritten as follows:

In California, Caltrans prepares a multi-year estimate of state and federal funds projected to be available for its capital program, and forwards it to the California Transportation Commission, a board appointed by the Governor, for review and approval. The Commission reviews and approves the fund estimate. Based on the final fund estimate, Caltrans and the several regional transportation planning agencies nominate projects for inclusion in a State Transportation Improvement Program (STIP), which lists specific projects, and submits it to the Commission for approval. Starting in 1990, Caltrans also prepares and submits a separate Highway System Operation and Protection Plan (HSOPP), which includes safety, rehabilitation, and operational projects on the state highway system. An annual budget proposal is also prepared by Caltrans, and submitted through the Governor to the legislature, which appropriates funds for the capital programs set forth in the STIP and HSOPP. However, funds are not allocated to individual projects by the Commission until they are ready to be advertised for bid.

See comment 9

Page 4, middle paragraph which begins with "Earthquake effects...":

Recommend consistent terminology for reference to "g" force. For example, in fifth and sixth lines from end of paragraph, reference is made (first) to "....between .26 and .29 percent of gravity ..." and (second) to ".... measurements of .11 and .13 in San Jose ...." We believe the convention would be .26 g, .29 g, .11 g, and .13 g respectively.

See comment 10

Pages 5 and 6, beginning with "Correcting deck weaknesses ...":

A major factor in the decision to give the "hinge restrainer" phase highest priority was that there was no available technology for either single - or multiple-column retrofit strengthening. When the "Phase II" program was presented to CTC in 1987, it was specifically made clear to the Commission that the technology did not exist even then.

See comment 11

- 1 -

The statement that "... no work had been done as of April 6, 1990, on the 392 single-column structures..." is wrong. Clearly, as the balance of the paragraph indicates, both research and design work had in fact been done on such structures, granted that no actual construction contract was yet underway. In addition, the Department has never withheld from allocation or advertising any retrofit project on which design was complete. The statement that "... some (single-column retrofit) project designs had been completed by June, 1988, but other projects were given priority in funding" is wrong. The statement on pp 10-11 that "...some project designs were completed by June 1988, but the districts did not complete the site work needed to forward the projects for funding approval...." helps to clarify what the auditors were told, but is still incorrect. In these cases, the "structures" element of some project designs may have been considered complete, but the final Plans, Specifications, and Estimates needed to advertise the projects were not complete with respect to items such as utility relocations, right of way acquisition, permits, etc., and the projects could neither be presented to the CTC for funding, nor advertised for construction.

See comment 12.

Page 8, "Funding has been available in the past ....":

The statement "although California began its seismic retrofit program in 1971, it did not begin earmarking funds for this purpose until 1987" is incorrect on two counts. First, California does not normally "earmark" any funds. In 1987 the CTC simply accepted the Department's recommendation to establish a lump-sum reservation as a matter of convenience, because the specific individual projects needed to implement the program had still not been identified (in part, at least, because the appropriate retrofit technology hadn't yet been identified). Second, "major" seismic retrofit projects were in fact included in STIP's prior to 1987, either as part of reservations or as line items projects ("minor" projects, with a few exceptions, have never been included in the STIP in any program area). Through the 1986/87 FY, 1260 bridges were retrofitted with hinge restrainers at a cost of about $54 million.

See comment 13.

Page 9, "California has not earmarked funds..."

Again, this paragraph is incorrect, for the reasons given above regarding the similar reference on page 8. Furthermore, the sentence "Funding for each project was taken from Caltrans' State Transportation Improvement Program; funds for the seismic retrofit program were not specified within the budget" implies that funds for other kinds of projects are specified in the budget. In fact, with very few exceptions, the budget never specifies funding for individual projects or even project types, and until 1990 funding for every project, not just seismic retrofit projects, was "taken from" the STIP.

See comment 14.

- 2 -

(Now, because of recent changes in statute, funds are "taken from" the STIP, the HSOPP, the TSM Plan, etc.)

Page 10, second para under "Competing priorities ...":

The statement that "... the districts received no additional resources specifically for retrofitting work" is incorrect. The resources assigned to the districts were based on the project workload from the STIP, which included the seismic retrofit program. In fact, where the capital program is concerned, the districts have not in recent years received support resources specifically for any project type.

See comment 15

The statement that "... safety and rehabilitation projects have been assigned priority based on the number of lives lost in previous incidents," and the attribution to "Caltrans officials" are misleading. Accident histories are one basis for preliminarily identifying potential project locations in certain categories of "safety" projects. Likewise the conclusion that "retrofit projects were accorded a relatively low priority because ... earthquake damage to state bridges had resulted in the loss of only two lives..." is misleading in its suggestion of a single, direct cause-and-effect relationship.

We believe it would be more accurate to say the Department considered there was no appreciable risk of loss of life due to catastrophic failure of bridges in any maximum credible earthquake, particularly once the hinge restrainers had been installed. To the extent guardrails, median barriers, and other safety projects were accorded high priority, it was because of the certainty that such projects would reduce the future loss of life.

Page 11, "Funding for all retrofitting work is uncertain":

See comment 16

Third and Fourth lines of first paragraph, the CTC does not "control Caltrans' overall budget." The audit report needs to reflect the distinction between the program, the budget, and fund allocations. While the CTC does, indeed determine which projects are included in the STIP (and, now, HSOPP, which is the relevant document where the retrofit program is concerned), the budget is determined by the Legislature and Governor. The CTC does also allocate budgeted funds to specific projects, including retrofit projects, but within the controls and constraints contained in the budget. In fact, the CTC can only allocate funds appropriated by the Legislature, which considerably limits the options to determine "... how it would make funds available to supplement the $60 million appropriated by the legislature for seismic retrofitting work."

The following are GAO's comments on CalTrans' letter dated May 16, 1990.

GAO Comments

1. We were asked to examine what CalTrans knew about the condition of the two collapsed structures, what funds were available and have been spent on seismic retrofit work in California, and what funds will be needed to complete California's seismic retrofit program. We were not asked to address safety concerns for the nation as a whole or to determine the adequacy of seismic safety standards endorsed by the federal government.

2. In the past, CalTrans' commitment has not been sufficient to ensure completion of the seismic retrofit program. Although CalTrans has renewed its commitment, it will not be fulfilled unless funds are diverted from other projects or the legislature appropriates additional funds.

3. CalTrans has received over $4 billion since 1975 for federal-aid highway programs that included seismic retrofit work as an eligible activity. The state chose to spend about $46 million—about 1 percent—of this on seismic retrofit projects, reflecting state-determined priorities. In addition, if the state had initiated column retrofit research and performed some of the column retrofit work during the last 18 years, the impact on any single year's budget would have been considerably less than it will be between now and the end of 1993.

4. We recognize that California made choices between retrofit work and other safety programs. However, we found that when these choices were made, seismic retrofit work received relatively low priority.

5. We do not say nor do we suggest that CalTrans knew that the Cypress Viaduct contained a flaw or that they ignored it. However, we revised the report language to use the term "weakness" to describe the hidden defect which, when placed under stress, had the potential to cause collapse. We did not evaluate whether the Cypress Viaduct met the design standards and codes of its day but, as we point out, CalTrans engineers now believe this design detail was a major factor in the structure's collapse.

6. Only one of the problems identified at San Fernando was corrected through the use of hinge restrainers. The potential for column damage and structural failure was identified, according to CalTrans, in 1971 and reemphasized in 1987. In contrast to CalTrans' assertion that no distinction was made between single-column and multicolumn bridges until after 1987, a 1978 CalTrans publication describing the 1971 earthquake's

effects portrayed single-column bridges as being "particularly" vulnerable to damage. Further, CalTrans officials considered multicolumn bridges as less vulnerable because of the additional stability provided by the additional columns. The technology to retrofit multicolumn bridges is not available.

7. We do not say that CalTrans engineers knew that the Cypress Viaduct was uniquely vulnerable to collapse or had any reason to specifically target it for review. CalTrans engineers told us, however, that if the program had progressed to the third phase, engineers reviewing the structure's plans would have discovered the column weakness.

8. Retrofit work was not finished with the completion of phase one in 1989; CalTrans engineers had long recognized the need to retrofit bridge support columns and had in fact planned to deal with these deficiencies in phases two and three of the retrofit program.

9. This paragraph was deleted from the final report because it was not considered necessary to include a detailed discussion of California's process for funding transportation projects in order to understand that the California Transportation Commission approved CalTrans' funding request for the seismic retrofit program.

10. It was decided that the discussion of the measurement of earthquake forces would best be presented as an appendix to the report. Therefore, this information is now incorporated as appendix III to the report. Per CalTrans suggestion, references to the percentage of gravity were changed to "g" force for consistency.

11. To say that the technology to retrofit either single- or multicolumn structures was not available in 1971, when the weaknesses were first identified, or in 1987, when the phase two funding program was presented to the California Transportation Commission, ignores the fact that CalTrans was responsible for developing the needed technology. Although a 1978 CalTrans publication stated that a contract would be awarded for column retrofit research in "the near future," the contract was not awarded until 1987.

12. We did not find that the Department withheld from allocation or advertising any retrofit project on which design was complete. However, we were told by several CalTrans engineering officials that retrofit

projects were not finalized, even though the structural designs were finished, because funds were not available to perform the construction work.

13. This paragraph was deleted from the final report because it duplicated information provided later in the report on funds provided for the seismic retrofit program.

14. This paragraph was revised to delete the reference to the earmarking of funds for the seismic retrofit program and to eliminate the implication that other types of projects were specified in the budget.

15. Although CalTrans uses a formula, which includes lives lost as well as other elements, to determine how projects in the state transportation plan will be ranked, CalTrans officials told us that the determining factor was the lives lost element.

16. CalTrans' budget is in fact determined by the legislature and approved by the governor, but the responsibility for allocating budget funds among projects has been delegated to the California Transportation Commission. As a result, if the legislature does not decide to increase CalTrans' budget to complete seismic retrofit work, the Commission will need to decide whether to reallocate funds already dedicated to other projects.

Objectives, Scope, and Methodology

On October 23, 1989, the House Appropriations Committee, in House Report 101-301, Further Continuing Appropriations, 1990, requested that we provide information on the collapse of the Cypress Viaduct section of Interstate 880 and the San Francisco/Oakland Bay Bridge during the October 17, 1989, Loma Prieta Earthquake. In accordance with subsequent agreements with the Committee, our objectives were to determine (1) what the California Department of Transportation (CalTrans) knew about the structures' vulnerability to earthquake forces before they collapsed, (2) what federal and state funding was available and expended in California to strengthen bridges subject to earthquake forces, and (3) what funding is needed to complete California's seismic retrofit program.

To accomplish our objectives, we interviewed officials from CalTrans; the Federal Highway Administration in Washington, D.C., and Sacramento; and the California legislature, as well as various experts within the seismic engineering community. We attended all sessions of the Governor's Panel on the Loma Prieta Earthquake, at which a broad spectrum of engineers, seismologists, geologists, and budget experts presented information on the Bay Bridge and Cypress collapse, the retrofit program, and the California and federal budget processes. We reviewed maintenance files for the two failed structures, state and federal budget documents, program priority policies and plans, and federal-aid highway program information.

We did not independently evaluate the design or construction plans to determine the structural adequacy of the Cypress Viaduct or the San Francisco/Oakland Bay Bridge or the technical reasons for the structures' collapse. Rather, we relied on CalTrans' information and opinions, views of experts presenting information to the Governor's panel, and various reports and studies published after the earthquake.

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